TIME-KEEPING IN LONDON.

REPRINTED FOR DISTRIBUTION BY THE

OBSERVATORY OF WASHINGTON UNIVERSITY, ST. LOUIS.

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IT is proposed in this paper to describe some special features of the instruments by which time is kept at the Royal Observatory, Greenwich, the means for correcting them, and the methods and instruments by which time-signals are distributed from the observatory to London and elsewhere.

The primary standard time-keeper of England is a sidereal clock kept in the basement of the Royal Observatory, Greenwich. This clock is of the best construction, and is, moreover, provided with the most approved apparatus for compensation and correction.

Experience has shown that the best results are obtained when the connection between the driving-weight and the pendulum of a clock is as slight as possible. This has been accomplished in the Greenwich clock by the use of an elegant escapement, the details of which are shown in Fig. 1,* representing a back view of the clock-train. The crutch-axis, supported by the arm (*c*) and the back plate (*b*) of the clock-train, carries an arm (*e*), attached at *f* to the left-hand pallet arm. The pallets are carried by the crutch-rod (*d*). At *g* is attached a detent projecting toward the left and ending in a light curved spring. Near the top of the escape-wheel this detent carries a jeweled pin which locks the wheel. The action is as follows: When the pendulum swings toward the left, the arm (*e*) lifts the delicate spring at the end of the detent, the wheel is released and drops forward so that a tooth presses against the face of the pallet and gives an impulse to the pendulum; the spring at the end of the detent immediately locks the wheel again, and the pendulum swings on freely to the left. When the pendulum swings to the right, the light spring at the

* Figs. 1, 3, 4, 5, and 6, have been taken from Lockyer's "Stargazing," through the courtesy of Macmillan & Co., London, publishers, by permission of the author.

end of the detent lets it pass without unlocking the wheel. The right-hand pallet is only intended to catch the wheel in case of

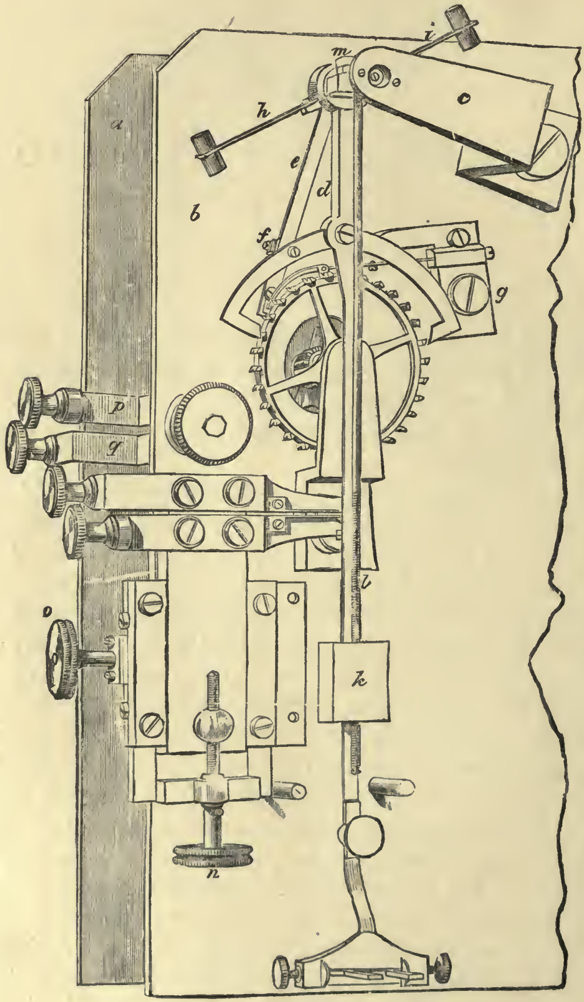

FIG. 1.—GREENWICH CLOCK ESCAPEMENT.

accident and forms no essential part of the escapement. Thus, it will be seen, the pendulum is quite free except during a part of every alternate second, when it releases the escapement and receives an impulse ; the seconds-hand, attached to the escape-wheel, moves only once every two seconds.

The most important source of error in the running of a fine clock is the change in the length of the pendulum due to change of temperature. Two methods suggest themselves of eliminating this error: 1. To put the clock where it will not be subject to changes of temperature. 2. To counteract the effect of changes of temperature. To this end various kinds of pendulums have been devised, notably the mercurial and gridiron forms, which are known under the general name of "compensating pendulums." At Greenwich the two methods are combined to insure complete success. The clock is placed in the magnetic basement of the observatory, where the temperature is as nearly uniform as possible, and apparatus is provided to annul the effect of any change of temperature which might occur.

Tests made with a mercurial pendulum disclosed the fact that the steel rod responded more quickly than the mercury to a change of temperature, and that consequently an appreciable interval of time was required for perfect compensation; a modification of the gridiron form, shown in Fig. 2, was therefore adopted. The pendulum was designed by Messrs. E. Dent & Co., of London, for the Transit of Venus Expedition (1874), but has since been used for the primary standard time-keeper of the United Kingdom. Its construction will be best understood by refer-

FIG. 2.—GREENWICH PENDULUM. ELEVATION.

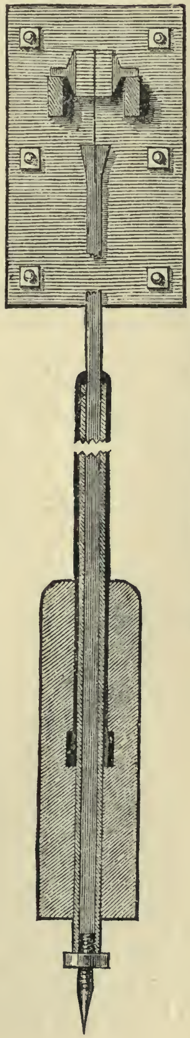

FIG. 3.—GREENWICH PENDULUM. SECTION.

ence to the section shown in Fig. 3. To the lower end of a steel rod, suspended in the ordinary manner, is attached the screw for rating the pendulum. On this screw and surrounding the rod rests a zinc tube, extending upward ; inclosing the zinc tube and attached to its top is a steel tube extending downward ; on a collar, at the lower end of the steel tube, hangs the cylindrical leaden bob, attached at its center. Slots and holes are cut in the tubes in order to equally expose all parts. The following table, taken from the official records of the Royal Observatory, is published by Messrs. E. Dent & Co., for the purpose of showing the performance of a clock with steel and zinc pendulum :

CLOCK—DENT 1914.

DATE.			Clock slow of Greenwich sidereal time.		Mean daily losing rate during each interval.	Average temperature of external air.
	Days.	Hours.	Minutes.	Seconds.	Seconds.	
1871—September	3	21	14	31·8	..	..
	17	21	15	34·1	4·4	62°
	24	21	16	2·3	4·0	54
October	1	22	16	34·2	4·5	50
	8	21	17	5·1	4·4	52
	15	21	17	36·9	4·5	46
	22	21	18	8·2	4·5	54
	29	21	18	37·8	4·2	47
November	5	22	19	7·8	4·3	47
	12	22	19	36·2	4·1	39
	19	21	20	5·8	4·3	35
	26	22	20	36·3	4·3	34
December	3	21	21	6·7	4·4	36
	10	22	21	33·9	3·9	30
	17	21	22	6·6	4·7	40
	26	0	22	45·2	4·8	42
	31	22	23	13·2	4·7	43
1872—January	7	22	23	46·3	4 8	42
	14	21	24	20·7	4·9	40
	21	21	24	54·2	4·8	39
	28	22	25	30·2	5.1	42
February	4	22	26	6·4	5·2	44
	11	22	26	41·4	5·0	47
	18	21	27	16·0	5·0	44
	25	22	27	50·0	4·8	45
March	3	21	28	24·1	4·9	46
	10	22	28	58·1	4 5	49
	17	21	29	31·2	4·8	45

During the whole time of rating, the clock was situated in a small hut erected for observing the Transit of Venus. No record of the temperature of the hut was kept, but the variations would be very similar to those of the external air, whose average temperature for each interval is given in the table.

The compensating action of the pendulum evidently depends upon the relative lengths of steel and zinc, and it is easily possible that great difficulty would be experienced in cutting and fitting tubes of exactly the right length ; to complete the adjustment a very delicate contrivance is added.

Two compound bars of brass and steel (*h* and *i*, Fig. 1), with small weights at their ends, are hung to the crutch-axis by means of a collar loose enough to be easily turned. The rods are so made that under normal conditions the brass and steel are of the same length, and the two bars are in the same straight line ; the center of gravity of the rods and the weights (regarded as one body) is therefore in the axis, and the weights are balanced in every position, no matter what angle the line of the rods makes with the plane of the horizon ; they affect the pendulum only by their inertia. But, when a change in temperature occurs, the brass and steel become of unequal length, owing to a difference in the co-efficients of expansion of the two metals, the rods are bent, and the center of gravity of the rods and weights is no longer in the axis, nor is it in the same vertical plane as the axis except when the weights are in a horizontal line ; so that an unbalanced force is introduced whose compensating action varies from a maximum when the weights are in a horizontal line, to zero when the weights are in a vertical line. To be explicit, suppose the rods to be horizontal and the brass uppermost, and let there be an increase of temperature. The brass will expand more than the steel, and, the rods being bent downward, the weights will be lowered. As the pendulum swings the weights swing with it, and are continually trying to get back to a horizontal position where they would balance each other ; if they were swinging alone, they would evidently swing faster than the pendulum, and therefore, being attached, they accelerate its motion. If the steel were uppermost, the weights would be raised with an increase of temperature and the pendulum retarded. If the rods were both vertical, a change of temperature would only throw the center of gravity of the two weights to one side or the other of the axis, but would not raise or lower it ; this would only introduce a continuous force tending to make the pendulum oscillate farther on one side than the other, but not affecting its rate. At intermediate positions between the vertical and horizontal, the change in the position of the center of gravity due to a change of temperature would vary with the angle made by the line joining the centers of gravity of the two weights with the plane of the horizon ; any required compensating action, between the limits above mentioned, for a known change of temperature, can therefore be obtained by setting the rods at the proper angle.

In order to make a small change in the rate without stopping the pendulum, the device shown in Fig. 1 has been employed: A weight (k) slides freely on the crutch-rod shown back of it in the figure, but is held by the screw on the end of the spindle (l) which hangs from the nut (m) at the crutch-axis. By turning the nut (m) the weight (k) can be lowered or raised, and this makes the clock gain or lose.

But the nicety of the correction of variations due to changes of temperature has brought to light variations due to another cause commonly quite overlooked; it has been found that the pendulum is affected by changes of barometric pressure. A change in the barometer of an inch and a half will sensibly alter the rate of the pendulum. The difficulty might be avoided by placing the clock in a

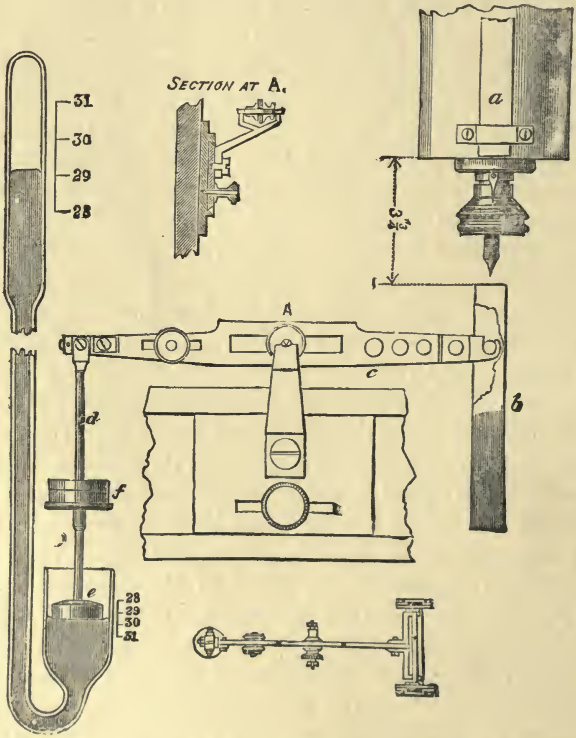

FIG. 4.—GREENWICH CLOCK: ARRANGEMENT FOR COMPENSATION FOR BAROMETRIC PRESSURE.

vacuum, but this is evidently impracticable. In the Greenwich clock the method shown in Fig. 4 has been adopted to counteract the effects

of barometric changes. To the pendulum-bob are attached two vertical bar-magnets, one in front (a) with the north pole down, the other at the back (and therefore not shown in the figure), with the south pole down. Below these and normally at a distance of $3\frac{3}{4}$ inches from them is a horseshoe magnet (b) which hangs on one end of a lever (c) nicely balanced on knife-edges at A ; the other end of the lever (c) rests by means of a rod (d) on a float (e) in the shorter leg of a siphon barometer. Counterpoises are added at f to balance the magnet (b). A plan of the lever on a smaller scale and a section at A are also shown in the figure. The barometer-tube is made so much larger in the shorter than in the longer leg that a change of one inch in the barometer would move the float in the shorter leg only two tenths of an inch. A rise or fall in the barometer causes a corresponding motion in the horseshoe magnet, and thus varies the intensity of its attraction for the magnets on the pendulum-bob. By proper adjustment this varying attraction is made to furnish the required compensation.

The small error which remains, notwithstanding the above-detailed provisions for correction, is allowed to accumulate, but is determined daily (unless clouds prevent) by transit observations,* so that the exact sidereal time is always known.

The standard sidereal clock registers its beats upon the chronograph record ; controls, by electric connection, all the sidereal clocks in the different rooms of the observatory ; and drives a sidereal chronometer (b, Fig. 5), in agreement with itself, in the computing and time-distributing room.

The secondary regulator of the time of England is the mean solar standard clock at the Royal Observatory, which was specially erected in 1852 for service in the time-signal system, of which it is now the most important instrument. This clock has a seconds-pendulum, which closes an electric circuit as it swings to the right. An electro-magnet in the circuit lifts a small weight, which is discharged upon the pendulum as it swings to the left, and gives it an impulse ; this being repeated at each vibration is sufficient to keep it in motion. The pendulum also closes other galvanic circuits—one as it swings to the right, another as it swings to the left—which send currents alternately positive and negative through electro-magnets, alternately attracting and repelling bar-magnets fastened to an axis, which thus receives a

* The difference between the clock-time of the transit of a star over the meridian (corrected for errors of position of the instrument, and for "personal equation") and the right ascension of the star for the day, taken from the nautical almanac, is the error of the clock.

reciprocating motion. An arm projecting from this axis moves the seconds-wheel one tooth forward each second; proper gearing gives motion to the minute and hour wheels.

The mean solar standard, besides controlling other clocks, to be enumerated later, drives a seconds-relay (*a*, Fig. 5), which controls a mean-time chronometer (*c*).

All the clocks controlled by the mean solar standard are required to indicate exact Greenwich local time; the error can not therefore be allowed to accumulate, and the means of correction are provided. Carried by an arm projecting from the pendulum-rod of the mean solar standard is a magnet, five inches long, which swings just over a hollow galvanic coil, called "the accelerating or retarding coil," fastened to the clock-case and operated by a special battery. The attraction or repulsion, between the magnet and the coil, produced by sending currents in opposite directions, gives any required acceleration or retardation to the pendulum. Care must, of course, be taken that the correction be not made too quickly, else the clock, instead of being controlled by the current, will break away from control, and the error will be increased. It is now so arranged that the current will produce a correction of one second in about ten seconds. The correction is made as follows: Between the sidereal chronometer (*b*, Fig. 5) and the mean-time chronometer (*c*) there is a commutator (*d*). By moving its handle toward the right, a current is sent through the "accelerating or retarding coil" which accelerates the mean solar standard; by moving the handle toward the left, the current goes through the coil in the opposite direction, and retards the mean solar standard; in the intermediate position (shown in the figure) no action takes place. The operator, having ascertained the error of the sidereal standard and its sympathetic chronometer, by astronomical observation as described, applies this error to the face-reading of the sidereal chronometer, and gets the exact sidereal time; by simple reduction he finds the corresponding mean solar time, and, by comparison, the error of the mean-time chronometer; he then moves the handle of the commutator, and corrects the error of the mean solar standard, and of all the clocks controlled by it, without leaving his position in the computing-room. This correction can be made at any instant when the exact time is desired; it is usually made at 10 A. M. and 1 P. M., because at those hours a general distribution of time-signals takes place.

The mean solar standard serves for the distribution of accurate time in the following ways:

Nearly all the mean-time clocks in the Royal Observatory are driven by the standard clock; they are, in fact, simply dials whose hands are

moved in the same way and by the same battery as the hands of the standard itself. These clocks are placed in the various rooms of the observatory, so that the astronomers have the exact time close to any

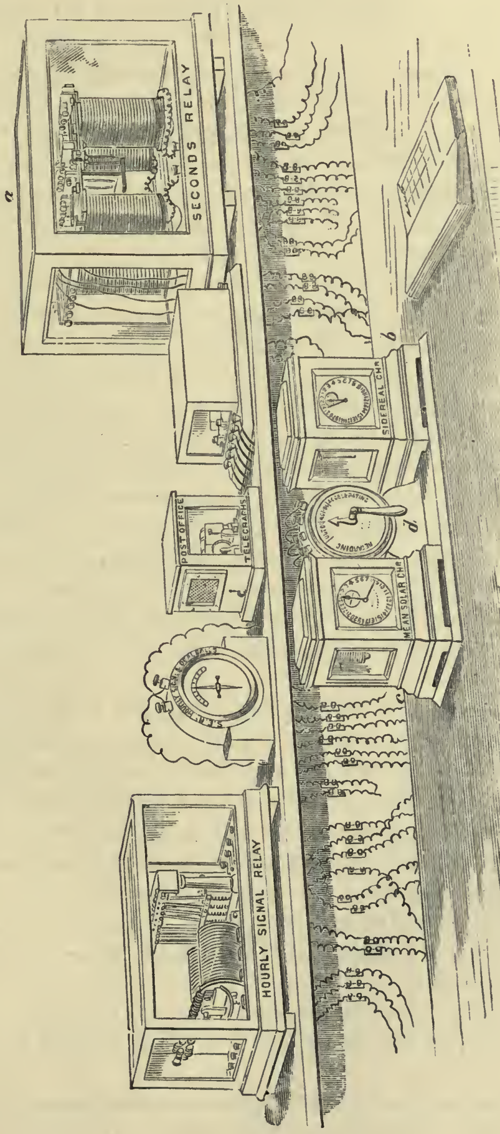

Fig. 5.—Arrangement for correcting Mean Solar Standard Clock at Greenwich.

of their instruments. One of them is in the wall surrounding the grounds, and will be familiar to every one who has visited the observatory; several are placed in the chronometer-room, where the navy and other chronometers are corrected and regulated.

The seconds-relay (*a*, Fig. 5), already referred to, is also driven by the mean solar standard.

Until 1880 the standard clock controlled, by seconds-beats, a number of clocks on a private wire in London, which were made to beat synchronously with the standard by an application of the Jones system,* in which the electric current is used, not as a driver, but as a regulator of clocks already running with small error and by means of their own motive powers. This plan, though still used within the observatory, has been abandoned in London.

With the standard clock is connected another electric circuit, open in two places. These are both automatically closed by the clock, one at the end of each minute, but the other only for some seconds on either side of the end of each hour; so that they are both closed only at the end of each hour, and then only can the current pass.

This hourly current acts on the magnet which drops the Greenwich time-ball daily at one o'clock, and on the magnet of the hourly relay (to the left in Fig. 5) which completes several independent circuits, each controlling a separate line of wire. One of these extends to the central telegraph station at the General Post-Office in London, and another to the London Bridge Station of the Southeastern Railway. The bell and galvanometer marked in Fig. 5 "P. O. Telegraphs" and "S. E. R. Hourly Signal and Deal Ball" show the passage of these currents.

Thus far the service is under the control of the astronomer royal, and he holds himself responsible to send the signals described along each line every hour of the day and night with the greatest attainable accuracy. The signals are generally correct within one tenth of a second of error. Should, however, by any accident, an hourly signal be in error, even to half a second, another signal is immediately sent, announcing that the last was not reliable. Special pains are then taken that the next hourly signal be correct. Here the responsibility of the astronomer royal (except for the dropping of the Deal ball, to be explained later) ends.

On the other hand, it is to be remarked that the Post-Office Department, which undertakes the distribution of these signals to London

* For an illustration of the Jones system for regulating clocks at a distance, see article on "Time-keeping in Paris," "Popular Science Monthly," January, 1882.

and the country, agrees to furnish subscribers, not with correct signals, but with the signals which they receive from Greenwich. The Greenwich signals, however, being considered everywhere in England

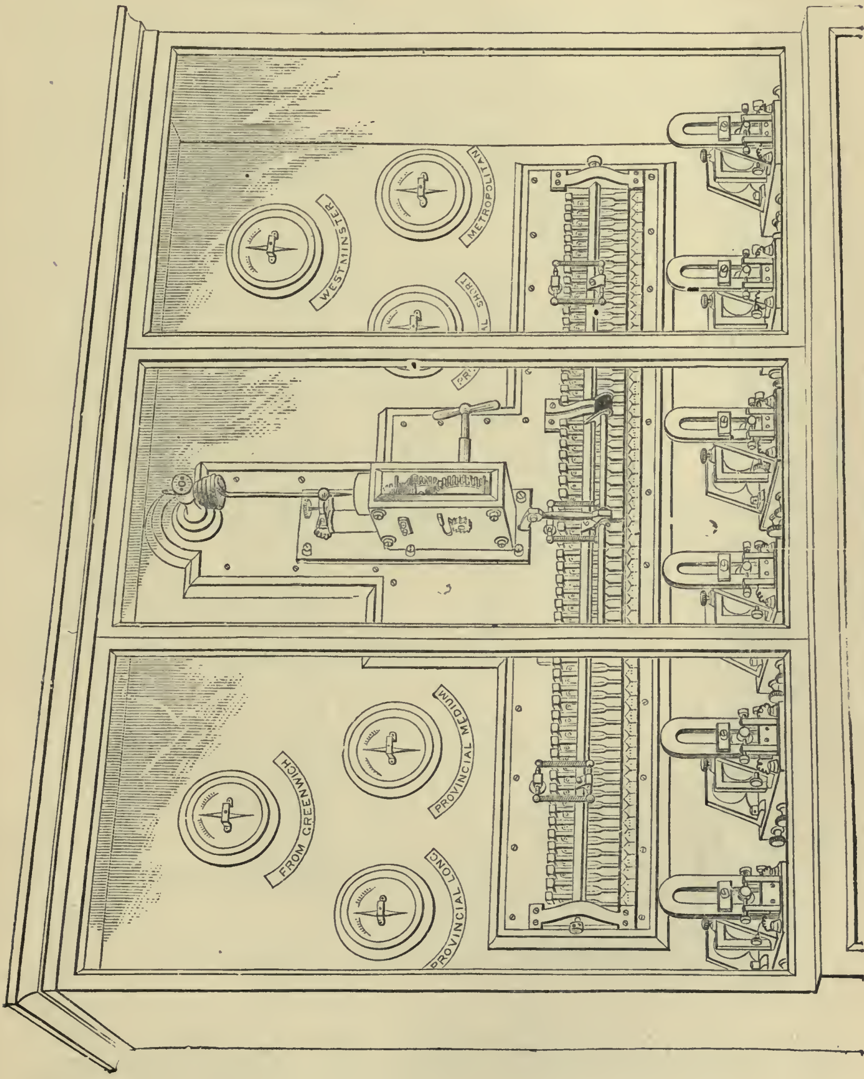

Fig. 6.—The Chronopher.—Perspective.

as absolutely correct, constitute a standard from which there is no appeal.

The distribution of the Greenwich signals from the General Post-Office in London is effected by means of the Chronopher or Time-

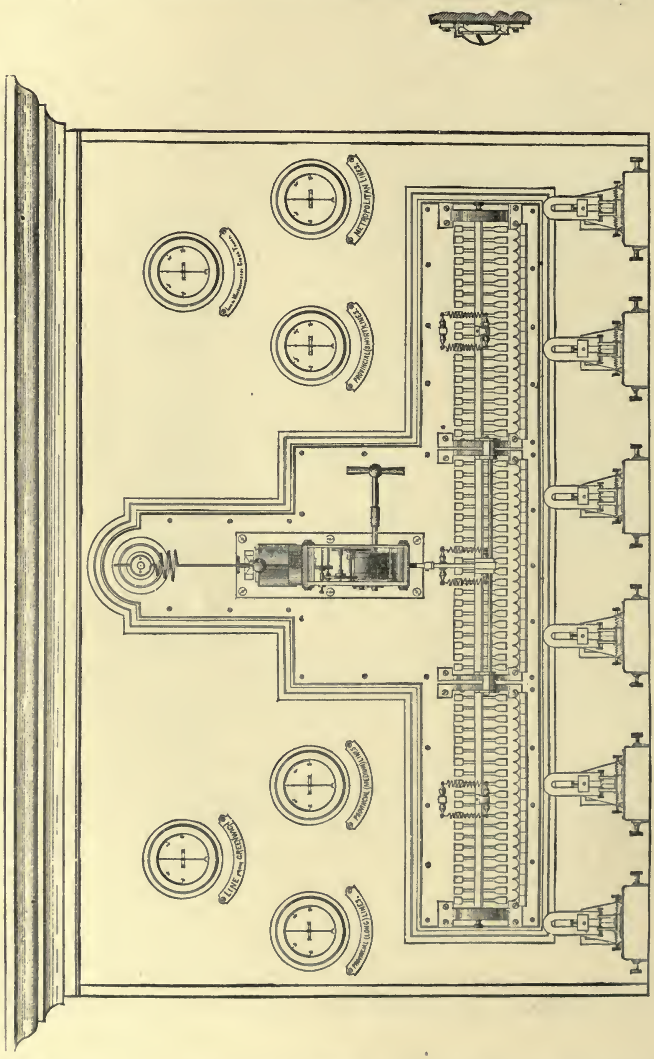

Fig. 7.—The Chronopher.—Elevation.

carrier,* shown in perspective in Fig. 6, and in front elevation in Fig. 7.† To this instrument the hourly signal from the observatory is sent

* There are actually two of these; the one shown in the figure is the new and larger one.

† For a description of the chronopher, from which the above is condensed, and for

by means of a special under-ground wire. Branching out from it are four groups of wires : 1. *Metropolitan*, running to points in London only. 2. *Provincial Short*, to points not more than fifty miles from London, as Brighton, etc. 3. *Provincial Medium*, to points farther away, as Hull, etc. 4. *Provincial Long*, to extreme points, as Edinburgh, Belfast, etc.* The ends of each of the four groups are brought together, and each group has a separate relay, in order that the shorter may not unduly deprive the longer lines of their share of the current. The four relays are all worked by the hourly signal from Greenwich, and therefore act simultaneously. The lines of the *Metropolitan group* are used only for time purposes, and are therefore always connected with their relay, and distribute the signals hourly. But the lines of the other groups are in use generally for ordinary telegraphic purposes, and distribute time-signals only at ten and one o'clock. At these hours, therefore, the wires must be switched off from their ordinary duty, and placed in communication with their respective relays to be ready to receive the time-signals. The electrical working of the apparatus which accomplishes this will be understood by reference to Fig. 8.† Under normal conditions, the current from the observatory passes directly through the chronopher, and out at the galvanometer G′, to the tower-clock at the Houses of Parliament, Westminster. This clock has a gravity escapement, and a metallic compensating pendulum, very similar to the pendulum of the Sidereal Standard, already described, and runs with a rate of less than one second per week. The current from Greenwich in no way controls the Westminster clock, but is simply used for rating the clock by comparison ; when change of rate is necessary, weights are added or removed at the pendulum.

Each of the line wires is in permanent connection with one of a set of jointed vertical bars (B, B′, B″), which, except at the times for the signal, are kept in contact by springs with cocks in the circuit of the wire ; but at the times for the signal a long metallic bar (C) acting as a cam (better shown in Fig. 7, in front of the vertical bars), is made by clock-work to disconnect all these bars from their instruments. The bar (C) is divided into three parts, corresponding to the long, medium, and short provincial lines, insulated from each other, and connected respectively with the bars of the relays (V, V′, V″) through the galva-

drawings from which Figs. 7, 8, and 9 have been made, the writer is indebted to William H. Preece, Esq., Superintendent of Telegraphs, London.

* The Greenwich signals are sent into Ireland only for purposes of comparison ; Dublin time is used throughout the island.

† The small figures 1, 2, 3, 4, to the right of Fig. 8 and to the left of Fig. 9, show the connection between the wires

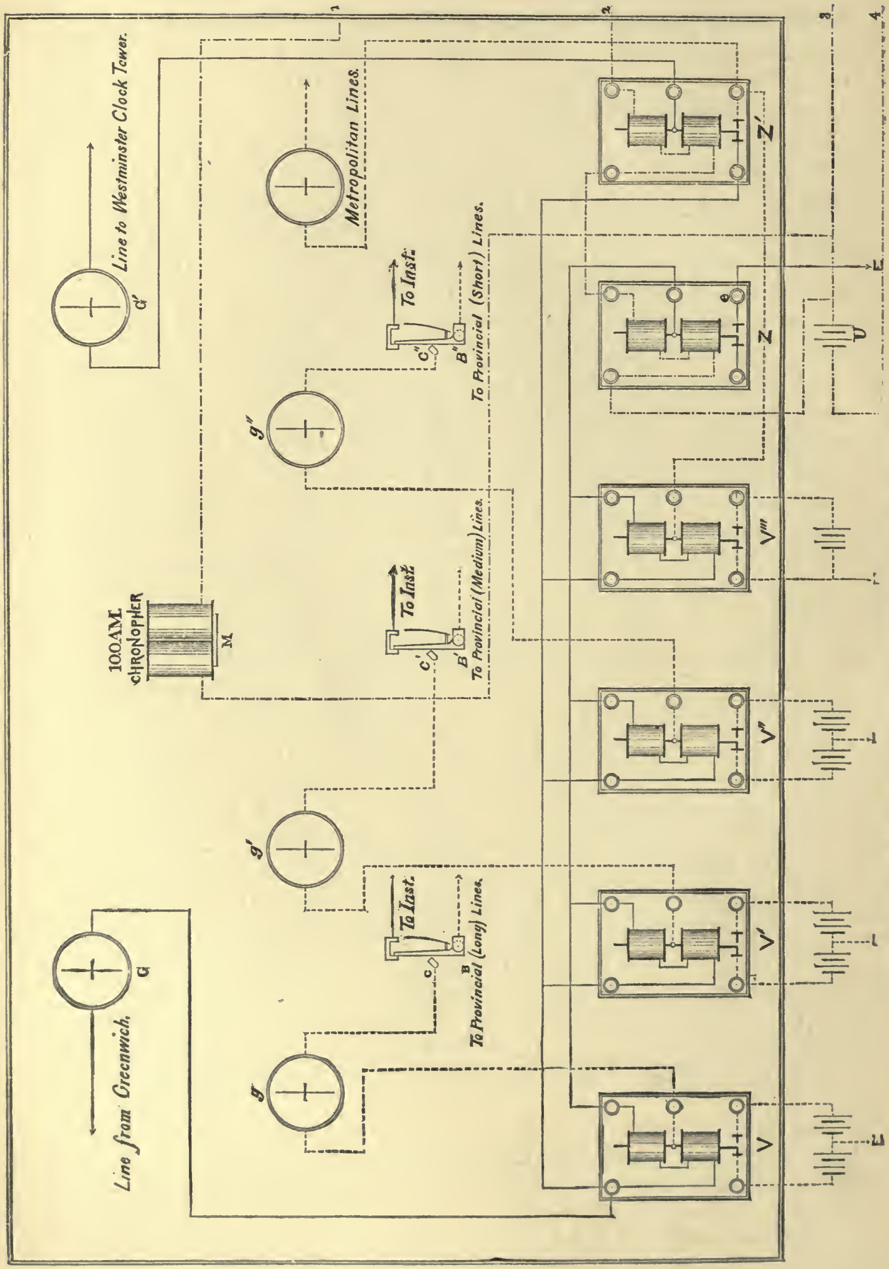

FIG. 8.—DIAGRAM SHOWING ELECTRIC CONNECTIONS OF THE CHRONOPHER.

nometers (g, g', g'', Fig. 8). The left or rest contacts of these relays are in connection with the zinc poles of separate batteries, whose copper poles are grounded, so that, when the bars of these relays are put in connection with the line wires, a zinc or "preliminary" current is ready to be sent out; this current prevents the distant relays from being actuated by contacts or accidental currents, and serves as a warning signal. The right-hand contacts of the relays are connected respectively with the copper poles of separate batteries whose zinc poles are grounded, so that, when the bars are moved over to the right (which is done by the incoming Greenwich current), the outgoing current is reversed, and this constitutes the signal. The relay V‴ is for distributing the signals only to points in the metropolis, and, as the wires on these lines are under ground, no "preliminary" current is necessary.

The mechanical operation of the apparatus is as follows: On the clock (R, Fig. 9) there is an ebonite wheel (W) in which are two notches (N, N′) corresponding to 10 A. M. and 1 P. M. Shortly before 10 A. M. the pin (P) on one arm of the forked lever (L) falls into the notch (N), allowing the end (Q) of the other arm to rest on the ebonite hour-wheel (T). About two minutes before the hour, the end (Q) comes against the contact (S), and completes the circuit of the local battery (U, Fig. 8) through the starting magnet (M, Fig. 9) and sets the clock-train (shown in Fig. 7) in motion, pressing the cam (C) against the vertical bars, disconnecting them from their instruments, and connecting them respectively, in groups as already shown, with the relays (V, V′, V″), in readiness to send a "preliminary" current to the line wires. At ten seconds to the hour an insulated pin (i, Fig. 9) on the wheel (T) lifts the lower arm of the forked lever (F), so that its upper arm comes in contact with a small cam on the arbor of the escape-wheel (K). This contact closes the circuit of the battery (U) through the coils of the two relays (Z, Z′). The relay (Z) puts on the earth connection at (E), for the four relays (V, V,′ V″, V‴), so that the current from Greenwich may be received and divided between them, while the relay (Z′) disconnects the Westminster clock-wire and connects it with the metropolitan lines to receive the signal from the relay (V‴). The relays (V, V′, V″, V‴) have a resistance of 5,000 ohms to allow of the splitting of the current. At precisely ten o'clock the Greenwich signal reverses the current on the lines, and thus gives the exact time. At ten seconds past the hour the contact between H and K is broken, the relay-bars go back to their normal position, the train-work moves away the cam (C), and restores the vertical bars to connection with their instruments.

The apparatus which effects the shunting at one o'clock is somewhat

different in construction. The pin (P, Fig. 9) falls into the notch (N′), a pin (p) on the wheel (W) coming against the arm (I) of the forked

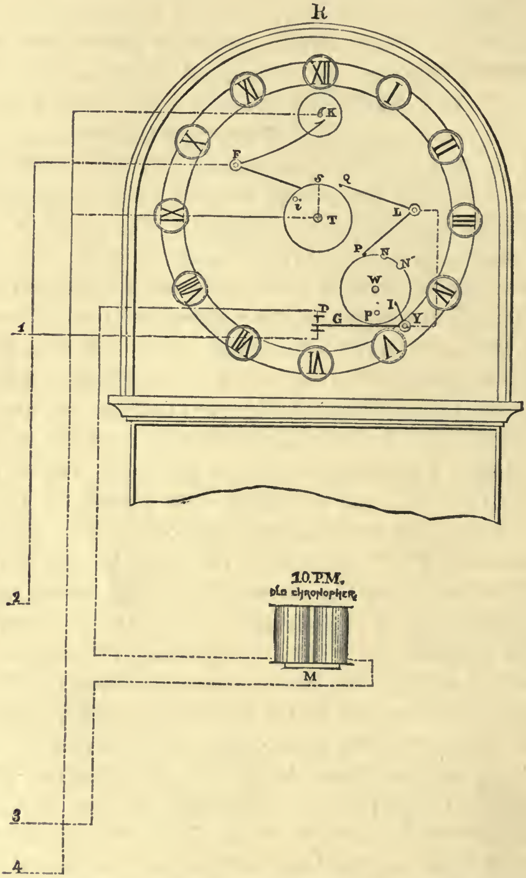

Fig. 9.—Diagram showing Electric Connections of Clock with Chronopher.

lever (Y) raises the flexible arm (G) against the upper contact (D), so that the circuit of the local battery (U) is closed through the starting magnet (M), which operates the one o'clock train-work.

Wires which receive both the ten and one o'clock signals pass through both switching arrangements.

For the hourly currents on metropolitan lines the relay (V‴) serves, by closing the circuit of the battery (U) at the contact (K), the rest of the apparatus remaining inoperative.

The actual interval during which the Greenwich as well as the provincial wires on which the time-signal is distributed are kept in circuit being only twenty seconds, the chance of interruption from contact currents is reduced to a minimum.

The batteries in use are large Leclanché cells, and the power is distributed as follows :

	Copper or "time" battery.	Zinc or "preliminary" battery.
Long lines	80 cells.	60 cells.
Medium lines	60 "	45 "
Short lines	40 "	30 "
Metropolitan lines	40 "	.. "

The Greenwich signal, thus distributed by the chronopher, goes to all parts of the kingdom, and affects receiving instruments provided for the purpose. These are of various kinds ; ordinary telegraphic sounders, electric bells, and galvanometers have been used with success to note the arrival of the signal. The current has also been made to drop time-balls on the tops of buildings, to expose a model time-ball to view, and to fire guns.

To test the accuracy of the signals, experiment has been made by returning a wire to Greenwich from the chronopher, and comparing the signal received on this wire with the signal sent from the observatory ; no difference could be perceived between the indications of two galvanometers placed side by side showing the passage of both currents. The signals were thus shown to be entirely reliable. But it does not seem likely that the chronopher will be introduced elsewhere, because simpler means have been devised for splitting up the current and distributing the signals.

The whole system is under the control of the Post-Office Department. They own the wires—which, except in London, are the ordinary telegraph-wires—and therefore contract to keep them in order, to clear them each day at the signal-times, and to deliver at these times the Greenwich signal. Maintenance of lines and apparatus not the property of the department is undertaken by the department for any period not less than one year at specified rates. A simple form of agreement has been prepared, which every renter is required to sign. This agreement, as a rule, is for not less than three years, and is terminable at three months' notice given previous to the end of the fixed term, or, failing such notice, on payment of such sum as the department may accept instead. But where the expense of construction is considerable, the term must not be less than from five to seven years, the latter period being stipulated when the proposed line is in an out-

lying district and would be specially provided for a single renter, and when it is not probable that there would be other renters.

The annual charges for the use of wires and apparatus are as follows :

From London to the country : * For the 10 A. M. signal, £12 to £17 = $60 to $85. For the 1 P. M. signal, £27 to £32 = $135 to $160. In London : For the hourly signal within a radius of two miles from the General Post-Office, £15 = $75. But if the person desiring the signal is off the line of the telegraph, he must pay, besides a stipulated rental, an additional sum for the use of the wire which the department is compelled to put up specially for him. The rental is in all cases payable yearly in advance.

In 1880 there were one hundred subscribers to the system, of whom nineteen were in London, and eighty-one scattered through England, with a few in Scotland and Ireland.

Besides this general automatic distribution of the time-signals, a considerable distribution of the 10 A. M. signal goes on by hand. At that instant the chronopher makes a sound which an operator sits ready to catch by ear. Upon hearing it he immediately dispatches a signal by the ordinary telegraphic instrument, and this signal is received at six hundred or more places, which again serve as distributing points for more distant places. These are usually railway or post offices in towns not supplied by the chronopher, which by virtue of authority become the regulators of the clocks of the surrounding district.

The wire from the observatory to London Bridge carries signals hourly from the mean solar standard to a clock at the station of the Southeastern Railway, which by changing connections sends Greenwich time to different stations along the line as may be required. For this service the Southeastern Railway gives the observatory the use of its wire daily, for a few minutes, at 1 P. M. At this time the current from the observatory drops the time-ball at Deal, which was erected in 1855, to give time to the shipping in the Downs, and is the only official coast time-signal. The ball in falling sends a "return" signal to the observatory. The record shows that about once in two months high wind prevents the raising of the ball, about once in six weeks it fails to fall on account of some fault in the electric connections, and about once a year it drops out of time. Under such circumstances it is dropped correctly at 2 P. M.

* Difference in charge for the same signal depends on the length of wire which the department is compelled to put up specially for the subscriber. The one o'clock signal is more expensive, because the wires are busier with telegraph duties at that hour than at 10 A. M.

By special arrangement with the observatory a few London jewelers receive the hourly Greenwich current on private wires. This they use for the correction of their own time-keepers and in some cases for distribution. Prominent among these are the Messrs. Barraud & Lund, of Cornhill, who have patented a method for the synchronization of clocks. Their plan is put forward as a simple and effectual means of setting any number of ordinary clocks to the same standard time. All attempts to control clocks have been set aside as impracticable, and a system adopted whereby the clock is automatically "set to time" every hour, or at such intervals as may be arranged. The apparatus can here be described only in brief. There are three essential parts, the *standard clock*, the *distributor*, and the *synchronizer*.

The standard clock is an astronomical regulator with mercurial pendulum and dead-beat escapement, and closes an electric circuit at the sixtieth second of each hour. Another regulator, technically called "Lobby," is for use in case of accident to "Standard." They are so connected that a single failure of "Standard" to send out a signal at the proper time brings "Lobby" into action for the next signal, and, in order that "Lobby" may always be ready for service, an intentional breakdown of "Standard" occurs automatically at eight each morning, and the nine o'clock signal is sent out by "Lobby"; which of the two is in operation is shown by indicators connected with the clocks (Fig. 10).* Should a breakdown occur, the indicator of "Standard" would show *missed*, and that of "Lobby" *at work*.

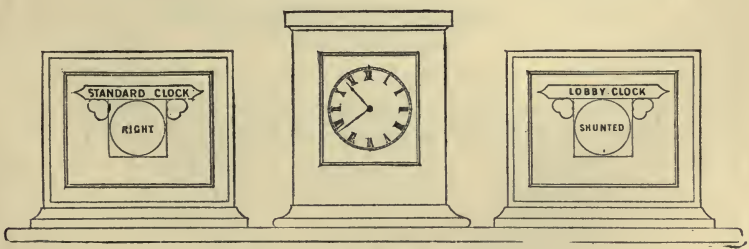

FIG. 10.—BARRAUD AND LUND'S INDICATORS.

The error of the standard clock is determined daily by comparison with the Greenwich signal. An ordinary dotting chronograph is set to the standard clock, and the Greenwich signal makes a dot on the

* Figs. 10, 11, 12, and 13, have been reduced from drawings in "The Railway Engineer," London, by permission of Messrs. Barraud & Lund.

chronograph-dial which gives at once the error of the standard and can be read off at leisure. It is corrected by electric means. The pendulum carries a small permanent magnet which swings over a re-

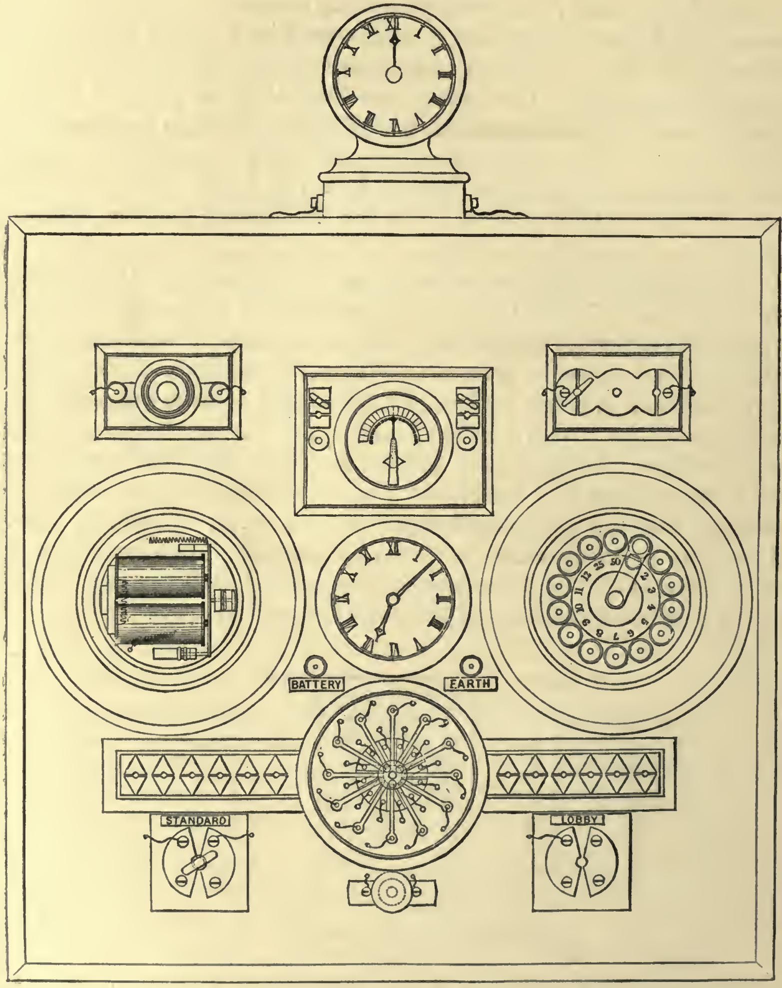

FIG. 11.—TEST-BOX.

sistance-coil about $\frac{1}{16}$ inch distant. The coil is connected with the commutator in the test-box (Fig. 11), consisting of a clock commutator, with plugs for "Standard" and "Lobby," a current commutator

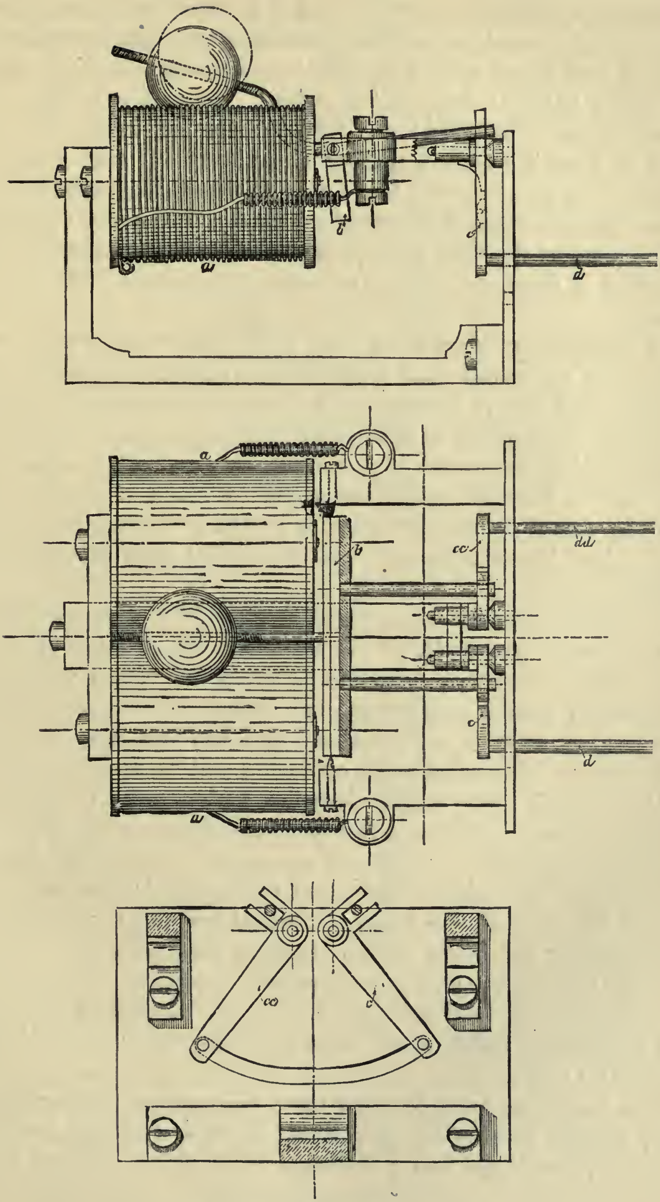

FIG. 12.—THE SYNCHRONIZER.

with plugs for "Fast" and "Slow," and a small time-piece, shown at the top. The time-piece has only a minute-hand, and is made so as to stop itself and break circuit at XII, but closes circuit when running. The working is thus : Suppose "Standard" is found to be slow. Plugs are inserted for "Standard" and "Slow," and the hand of the time-piece is set back a required number of minutes. It then runs to XII and stops. In this interval the action between the magnet and the coil has exactly corrected the standard clock. For every $\frac{1}{10}$ second of error the hand of the time-piece must be set back five minutes. When the setting is done, no further attention is required, all else being automatic.

The distributor (shown in Fig. 11) consists of twelve contact-springs, each connected with a line of wire running through a district of London, and twelve contact-screws, each connected with a battery. The springs converging to the center press up against a small plate, one inch in diameter, which is controlled by an electro-magnet in the circuit of the current which the standard clock sends out hourly. When the signal comes, the plate is pulled down and presses every spring against its contact-screw, and the signal goes out over each of the lines.

The synchronizer is the receiver of the signal, and consists essentially of an electro-magnet, in the circuit of one or other of the lines from the distributor, with armature carrying two counterpoised levers each provided with a projecting pin. When the signal arrives, the electro-magnet attracts its armature, and the two pins are brought close together. The mechanical operation will be understood by reference to Fig. 12, where a side elevation, a plan, and a front elevation are shown. This apparatus is fastened to ordinary clocks just back of the dial-plate (Fig. 13). A curved slot is cut through the dial for a short space on each side of XII, and through this the pins project. When, at the end of the hour, the signal arrives, the two pins are pushed together and bring the minute-hand exactly to XII. The position of the pins before and just after the operation is shown in Fig. 14. Evidently the clock must not be in error more than two minutes or so ; but, as the hand is set every hour, any ordinary clock can be kept right by this device.

Other ingenious arrangements have been added to guard against danger, always present to long lines of wire, and for testing the condition of the lines, but a description of them can not here be given.

The advantages claimed for the system are :

1. That any number of clocks of any varying sizes can be synchronized to any agreed standard time-keeper.

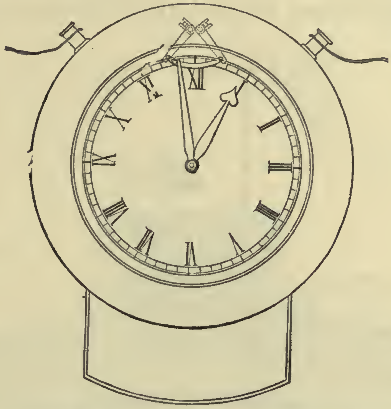

FIG. 13.—FACE OF CLOCK WITH SYNCHRONIZER ATTACHED.

2. That the mechanism is, when not in momentary use, entirely detached from the works of the clock.

3. That it can be applied to existing clocks.

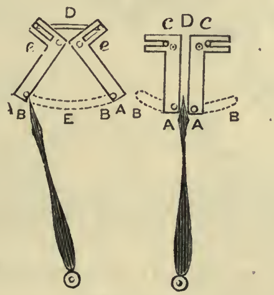

FIG. 14.

4. That any failure in the transmission of the time-current leaves the clock going in the ordinary way, to be "set to time" by the next completed current.

5. That the clocks are kept to time whether having otherwise either a gaining or losing rate, even if such rate amounts to many minutes a day.

In London the system has been in successful operation for about five years, and has been used over a wire four hundred miles long.

The subscribers number about five hundred, among them many railroads and public institutions.

In connection with the synchronized clocks, Messrs. Barraud and Lund have also established time-bells and flashing-signals, which afford

Fig. 15.—Barraud and Lund's Time-Bell.

time-signals both to the ear and eye. These are shown in Figs. 15 and 16. The bell is an ordinary electric bell, and is rung by the regulating clock, which closes the circuit at the instant the signal is desired. The flashing-signal consists of a red vertical disk on a vertical axis, which normally shows only its edge, but is made to revolve once on its axis in four sudden jumps, by simple mechanism in connection with electro-magnets, when the regulator, by closing the circuit, sends the current. The appearance is that of two flashes of red as the disk revolves.

In many places where noise prevents hearing a bell, the flashing-signal becomes a necessity. It is in use at the London Stock Exchange, and serves to indicate the exact instant of noon.

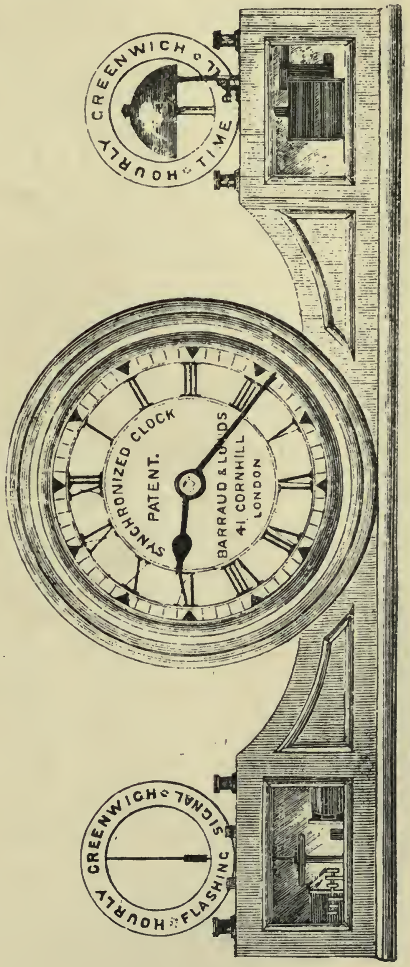

FIG. 16.—BARRAUD AND LUND'S TIME-BELL AND FLASHING-SIGNAL.

The method of synchronizing clocks is becoming rapidly popular throughout the world, and has been patented in most civilized countries. It is already in use in Australia and South America, and in some of the countries on the Continent of Europe. In this country, at New Haven, Connecticut, a "Standard Time Company" has been formed, who have bought the patent for the whole of the American Continent, and are now engaged in manufacturing synchronizers. An effort will be made by them to bring about a concerted system of time-signaling throughout the country. Local affiliated companies will be formed, and there is little doubt that the great simplicity and practical success of the method, combined with its cheapness, will secure its extensive adoption in all the large cities of the country.